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Space as a Special Frame and Starlight Aberration

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Abstract

It is generally accepted that the relevant velocity in the calculation of starlight aberration is the velocity of the Earth in its orbit around the Sun. We contend that, for distant stars or galactic sources which appear fixed over long periods of time, irrespective of their motion, the correct velocity for the calculation is the Earth's velocity relative to space, i.e., relative to the thermal bath of 2.7°k Cosmic Microwave Background (CMB). Our result for the starlight aberration constant differs from the commonly accepted value by approximately 0.3 seconds of arc.

Key Words: Starlight aberration; Cosmic microwave background; Lorentz transformation

1 Introduction

Einstein [1] derived a relativistic form of the aberration equation. In this equation, which appears in textbooks, the relevant velocity is that of the observer relative to the source, similar to the Doppler shift. This derivation is based on the Lorentz transformation when applied to the issue of addition of velocities.

We contend that when the source is a distant star, or galaxy, which appears fixed over long periods of time, irrespective of its motion, it is the velocity of the observer relative to space which is relevant ("close" and "distant" are quantified below). This velocity, relative to space, is relative to the thermal bath of 2.7°k Cosmic Microwave Background (CMB), and measured by the Doppler shift of the CMB.

2 A Derivation and Calculation

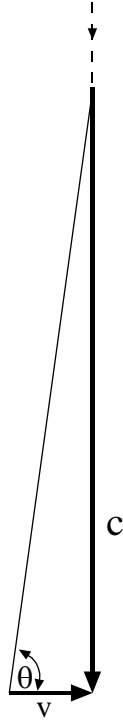
For a detached light pole, we follow Feynman's [2] idea for deriving the aberration equation. This derivation is based on a simple vector diagram, as shown in Fig. (1). Although we get the same equation as the textbooks, the relevant velocity in this case is the velocity relative to space **and not** the velocity of the observer relative to the source.

We now clarify the term distant source: Say we are expecting a deviation of ~ 0.3 seconds of arc from the conventional result for the angle of aberration of distant sources and we want a 10% experimental accuracy. The pole of light should then be defined to better than $0.03''$ during the time of observation.

For a time of observation of, say, 10 years, and a relative tangential velocity of, say, 500 km/sec, the source should be at a distance, d , of at least 10^5 light years, see Fig. (2).

Clearly, a source moving at a speed of 1000 km/sec and distant $2 \cdot 10^5$ light years shows the same aberration.

A Polar Star



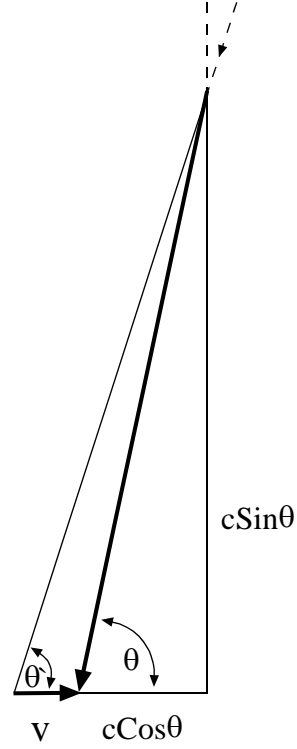
$$\text{tg}\vartheta' = \frac{\frac{1}{c}v}{\frac{\gamma}{c}} = \frac{\beta}{\gamma}$$

for $v \ll c$

$$\text{tg}\vartheta' = \frac{v}{c}$$

$$\left[\beta = \frac{v}{c} \quad \gamma = (1 - \beta^2)^{-\frac{1}{2}} \right]$$

General Case



$$\text{tg}\vartheta' = \frac{c \sin \vartheta}{\frac{1}{\gamma}(v + c \cos \vartheta)} = \frac{\gamma \sin \vartheta}{\beta + \cos \vartheta}$$

$$\sin \vartheta' = \frac{\gamma \sin \vartheta}{1 + \beta \cos \vartheta}$$

$$\cos \vartheta' = \frac{\beta + \cos \vartheta}{1 + \beta \cos \vartheta}$$

Fig. (1) Aberration of Starlight

Let us consider the simple case of a Polar star, as shown in Fig. (3). \mathbf{S}_t is the space system and light from a polar star comes along the z-axis. \mathbf{S}_0 is the solar coordinate system attached to the Sun. \mathbf{S}_0 moves with respect to \mathbf{S}_t at speed $V \sim 400$ km/sec along the y and y' axes, which are in the directions from the Aquarius galaxy and the Leo-Virgo galaxies.

$$\alpha_{\text{rad}} = \frac{L}{D}$$

$$\alpha = 0.03'' = 1.5 \cdot 10^{-7} \text{ rad}$$

$$1 \text{ year} \sim 3.16 \cdot 10^7 \text{ sec}$$

$$1 \text{ light year} \sim 9.46 \cdot 10^{12} \text{ km}$$

For a time period of $T = 10 \text{ years}$

$$\begin{aligned} D &= \frac{L}{\alpha} = \frac{v \cdot T}{\alpha} = \\ &= \frac{500 \times 10 \cdot 3.16 \cdot 10^7}{1.5 \cdot 10^{-7}} \cong 10^{18} \text{ km} \\ &\cong 10^5 \text{ Light years} \end{aligned}$$

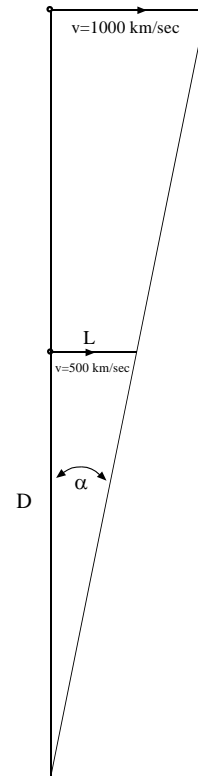


Fig. (2) A Distant Source

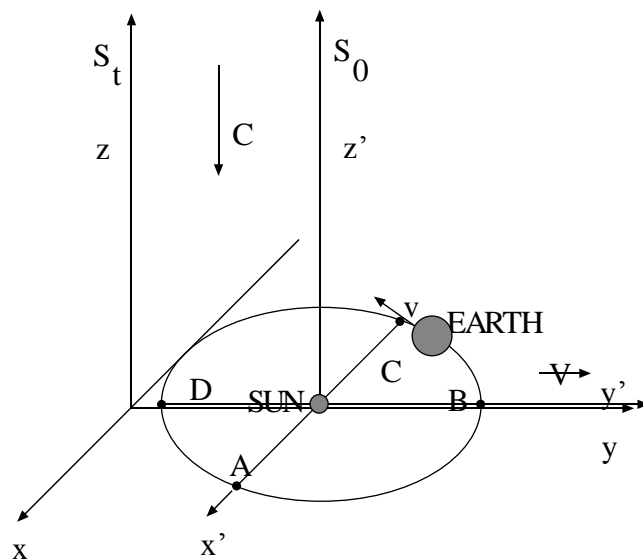


Fig. (3) The Aberration of a Polar Star

The Earth moves around the Sun with speed $v = 30$ km/sec. At points A, B, C and D the velocities of the Earth relative to S_t are: $|v_A| = |V| + |v|$ $|v_C| = |V| - |v|$

$$|v_{B,D}| = \sqrt{V^2 + v^2}$$

Taking the relativistic equation for the angle of aberration

$$t_g \vartheta = \frac{\beta}{\gamma} \quad (1)$$

where: $\gamma = (1 - \beta^2)^{\frac{1}{2}}$ and $\beta = \frac{v}{c}$

Using the numerical values:

$V = 400$ km/sec, $v = 30$ km/sec, $c = 300000$ km/sec gives the following results for:

ϑ_A , ϑ_C and $\vartheta_A - \vartheta_C$, which are:

$$\vartheta_A = 295.65'' \quad \vartheta_C = 254.39'' \quad \text{and}$$

$$\vartheta_A - \vartheta_C = 41.26'' \quad (2)$$

This result differs from the result obtained using just the orbital velocity, v , of the Earth

around the Sun. By using $t_g \vartheta = \frac{\beta}{\gamma}$ we get:

$$\vartheta_A - \vartheta_C = 40.99'' \quad (3)$$

Result (2) differs from (3) by approximately:

$$0.3'' \quad (4)$$

and the aberration lacks circular symmetry. These theoretical results should be compared with astronomical data and, if not conclusive, should lead to the collection of further observational data.

Note that (3) gives the known **constant of aberration**

$$\vartheta_{\text{Aberration}} = \frac{\vartheta_A - \vartheta_C}{2} = 20.495'' \quad (5)$$

In the Astronomical Almanacs the Constant of Aberration is not derived from observations. It is calculated based on the most recent data for the values of the velocity of light, c , and the orbital velocity of the Earth around the Sun, v . However, a systematic error of $\sim 0.3''$ in the observation of starlight aberration is reported by Scott (1963).

3 Summary

An observational confirmation, of our constant of aberration, would mean that space is indeed a special frame.

References

- [1] A. Einstein: On the Electrodynamics of Moving bodies (1905) Dover (1923)
- [2] R. Feynman: Lectures on Physics I, Addison-Wesley (1963)
- [3] F. P. Scott: The System of Fundamental Proper Motions in Basic Astronomical Data, University of Chicago (1963)